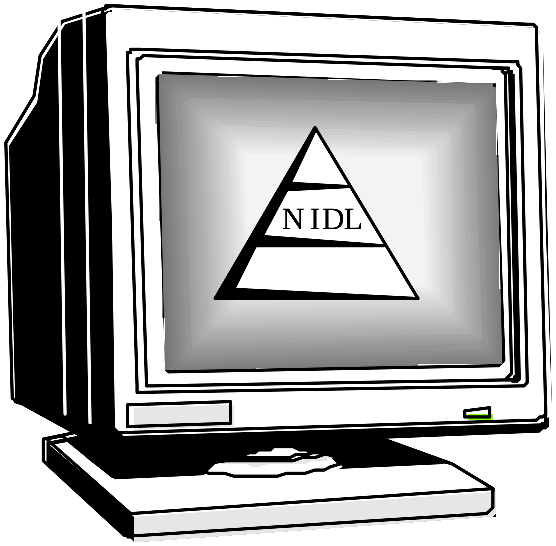

NIDL sequentially evaluated three samples of this monitor over a one-year period. It is the only commercially available monochrome monitor that has a perfectly flat face and other features that make it a potential candidate display device for NIMA Imagery Exploitation Capability workstations. Based on results of our evaluation of the third sample, NIDL cannot certify the Data-Ray DR96L monochrome monitor as being suitable for either monoscopic or stereoscopic operation in IEC workstations. NIDL rates this monochrome monitor as a “C” for monoscopic mode and “C” for stereo mode for the Image Analyst and Geospatial Information applications. Data-Ray engineers in Japan agreed with the results presented in this DR96L monitor evaluation report and have no plans to further improve the performance of the DR96L.

Evaluation of the Data-Ray DR96L 4 x 3 Aspect Ratio, 22-Inch Diagonal Flat Screen Monochrome CRT Monitor

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CONTENTS

NIDL IEC Monitor Certification Report

The Data-Ray DR96L Monochrome CRT Monitor

FINAL GRADES
Monoscopic Mode: C
Stereoscopic Mode: C

A=Substantially exceeds IEC Requirements; B= Meets IEC Requirements; C=Nearly meets IEC Requirements; F=Fails to meet IEC Requirements in a substantial way

NIDL sequentially evaluated three samples of this monitor over a one-year period. It is the only commercially available monochrome monitor that has a perfectly flat face and other features that make it a potential candidate display device for NIMA Imagery Exploitation Capability workstations. Based on results of our evaluation of the third sample, NIDL cannot certify the Data-Ray DR96L monochrome monitor as being suitable for either monoscopic or stereoscopic operation in IEC workstations. NIDL rates this monochrome monitor as a “C” for monoscopic mode and “C” for stereo mode for the Image Analyst and Geospatial Information applications. Our results are summarized below. Data-Ray engineers in Japan agreed with the results presented in this DR96L monitor evaluation report and have no plans to further improve the performance of the DR96L.

Some of the good features of the Data-Ray DR96L monochrome CRT monitor are a wide dynamic range that exceeds the 350:1 dynamic range specification in monoscopic mode, and a luminance of 164 fL for Lmax for a contrast ratio of over 1640:1 (32.1 dB dynamic range). Also, in 1024 x 1024 stereoscopic mode, a refresh rate as high as 122 Hz was verified by NIDL. For stereo viewing, we observed a luminance value of 32.5 fL through the Stereographics ZScreen and passive glasses which exceeds the required 30 fL minimum value in stereo. The extinction ratio of 28.4:1 also exceeds the 20:1 ratio required by the IEC specification.

The manufacturer made modifications to improve contrast modulation in this third sample monitor (serial number ROY019, received June 2001). However, this monitor still does not meet the minimum IEC contrast modulation requirement for 1 pixel on/1 pixel off in 35fL monoscopic mode (1600 x 1200 x 72Hz). Further, this monitor can produce a 1024 x 1024 stereo image at 60 Hz per eye, but it does not produce sufficient contrast modulation as required by the IEC Specifications.

The combination of the four measured results listed below prevents us from being able to justify an NIDL certification of the Data-Ray DR96L flat screen CRT monitor for NIMA IEC:

1. The contrast modulation in the horizontal direction as measured on a vertical grille test pattern with peak luminance set to 50% maximum luminance is not adequate to pass the NIMA IEC requirements. The CRT spot size appears to be satisfactory as evidenced by the high level of contrast modulation in the vertical direction, Cm-V, as measured on the horizontal grille test pattern. However, the low values of Cm-H (Zone A: 23% measured,

35% required; Zone B: 13% measured, 20% required) shows inadequate video amplifier bandwidth.

This conclusion is consistent with the difference in measured area luminance between horizontal and vertical grille patterns (1-pixel-ON/1-pixel-OFF) observed in the SMPTE RP-133 test pattern. As a diagnostic, we compared the area luminance of the vertical grille test pattern to the horizontal grille test pattern, and found that the vertical grille pattern is only 12.7 fL compared to 17.6 fL for the horizontal grille. The drop in luminance is indicative of insufficient video amplifier bandwidth. (For comparison, another monitor certified by NIDL for NIMA IEC had more uniform grille luminances: Hgrille = 16.7 fL, Vgrille = 15.8 fL).

2. Horizontal linearity fails the IEC specification (1.88% measured vs.1.0% maximum allowed).

3. Raster pincushion distortion along the bottom of the screen marginally fails the IEC specification (0.82% measured vs. 0.5% maximum allowed).

4. As patch size was reduced from full screen to 10% of full screen, luminance in 1024 x 1024 stereo mode increased from 215fL to 378 fL. Luminance of other monitors certified by NIDL for IEC change very little (less than 1%) over the same patch size range.

NIDL has certified alternative 1600 x 1200 pixel, landscape COTS monochrome monitors. The PIC 21si or its equivalent Siemens 21103L (stereo), the Siemens 21105L (stereo), the Orwin DEX2102L, and the Orwin 1988 easily pass the IEC specifications in both monoscopic and stereo modes and are rated “A”. These monitors have performance that substantially exceeds that of the Data-Ray DR96L Monochrome CRT Monitor, but at a somewhat higher cost.

The Data-Ray website is http://www.data-ray.com. The Clinton/Orwin website is http://www.cec-displays.com/index2.htm, and the Siemens website is http://www.siemens.com.

NIDL Evaluation Datasheet
Data-Ray DR96L ROY019 Monochrome Grayscale Monitor Tested August 2001

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC			
Addressability	1024 x 1024 min.	1600 x 1200	pass
Contrast Ratio (Dynamic Range)	350:1 (25.4dB)	367:1 (25.6 dB) tested 1640:1 max.	pass
Luminance (Lmin)	0.1 fL min ± 4%	0.1 fL	pass
Luminance (Lmax)	35 fL ± 4%	36.7 fL at tested 164 fL absolute max.	pass
Uniformity (Lmax)	28% max.	13.9 %	pass
Halation	3.5% max.	3.89%± 0.3% (3.57% to 4.24%)	fail
Correlated Color Temp	Not specified	11466 K	
Distance from Daylight Locus	Not specified	Not measured	
Screen Reflectance	Not specified	8.1%	
Bit Depth	8-bit± 5 counts	Not measured	TBD
Step Response	No visible ringing	Clean	pass
Uniformity (Chromaticity)	0.010 delta u'v' max. ± 0.005 delta u'v'	0.002 delta u'v'	pass
Pixel aspect ratio	Square, H = V± 6%	H = V	pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	19.375 inches	pass
Raster modulation (Lmax)	Not specified	27% V	
Cm, Zone A, 7.6 inch dia.	35% min.	23% H, 40% V	fail
Cm, Zone A, 40% circle, 9.58 inch diameter	35% min.	21% H, 32% V	fail
Cm, Zone B	20% min.	13% H, 22% V	fail
Pixel density	72 ppi min.	103 ppi	pass
Straightness	0.5% max ± 0.05%	0.82 %	fail
Linearity	1.0% max ± 0.5%	1.88 %	fail
Jitter	2 ± 2 mils max.	3.01 mils	pass
Swim, Drift	5 ± 2 mils max.	3.15 mils	pass
Warm-up time, Lmin to +/- 50%	30 mins. Max ± 0.5 minute	< 1 minute	pass
Warm-up time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	< 1 minute	pass
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 72 Hz	pass
Briggs Scores BTP#4 Contrast Delta-1, 3, 7, 15	No specification	12, 46, 57, 60	
STEREOSCOPIC with Z-Screen and passive glasses			
Addressability	1024 x 1024 min.	1024 x 1024	pass
Lmin	0.1 fL. Min. ± 4%	0.09 fL (1)	pass
Lmax	30 fL min ± 4%	32.5 fL (2)	pass
Dynamic range	24.77 dB min	25.6 dB	pass
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 delta u'v'	Not measured	pass
Refresh rate	60 Hz per eye, min	60 Hz per eye	pass
Extinction Ratio	20:1 min	28.5: 1	pass
Luminance Stability vs Fill Factor	No specification	75.8%	
AMBIENT LIGHTING			
Dynamic Range 22 dB (158:1)	No specification	Not measured	
Dynamic Range17.8 dB (60:1)	No specification	Not measured	

(1) Monitor BRIGHTNESS control advanced to maximum setting.
(2) Monitor CONTRAST control advanced to maximum setting.

1 mil = 0.001 inch
TBD To be determined.

Section I INTRODUCTION

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users. The NIDL is hosted by the Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics.

The present study evaluates a production unit of the Data-Ray DR96L monochrome CRT high-resolution display monitor. This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

The IEC requirements, procedures and calibrations used in the measurements are detailed in the following:

- *NIDL Publication No. 0201099-091*, *Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC),* August 25, 1999.

Two companion documents that describe how the measurements are made, are available from the NIDL and the Defense Technology Information Center at http://www.dtic.mil:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Draft Version 2.0. (ADA353605)*
- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

Other procedures are found in a recently approved standard available from the Video Electronics Standards Association (VESA) at http://www.vesa.org:

- *VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998.*
- *VESA Flat Panel Display Measurements Standard, Version 2.0, June, 2001.*

The IEC workstation provides the capability to display image and other geospatial data on either monochrome or color monitors, or a combination of both. Either of these monitors may be required to support stereoscopic viewing. Selection and configuration of these monitors will be made in accordance with mission needs for each site. NIMA users will select from monitors included on the NIMA-approved Certified Monitor List compiled by the NIDL. The color and monochrome, monoscopic and stereoscopic, monitor requirements are listed in the Evaluation Datasheet.

I.1 The Data-Ray DR96L Monochrome CRT Monitor

Manufacturer's Specifications

The specifications for the Data-Ray DR96 Portrait version of the DR96 Landscape monitor are at http://www.data-ray.com/pdfs/dr96f_back.pdf . Please refer to that web page for information as of January 2003 on the DR96 grayscale monitor.

I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p 5.

All measurements will be made with the display commanded through a laboratory grade programmable test pattern generator. The system will be operated in at least a 24 bit mode (as opposed to a lesser or pseudo-color mode) for color and at least 8 bits for monochrome. As a first step, refresh rate should be measured and verified to be at least 72 Hz. The screen should then be commanded to full addressability and Lmin set to 0.1 fL. Lmax should be measured at screen center with color temperature between D65 and D93 allowable and any operator adjustment of gain allowable. If a value >35fL is not achieved (>30 fL for color), addressability should be lowered. For a nominal 1200 by 1600 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability, addressabilities of 1200 x 1600 and 1024 x 1024 can be evaluated if the desired Lmax is not achieved at full addressability.

I.3. Equipment

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

The procedures described in this report should be carried out in a darkened environment such that the stray luminance diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m^2 (1mfL).

Instruments used in these measurements included:

- Quantum Data 8701 400 MHz programmable test pattern signal generator
- Quantum Data 903 250 MHz programmable test pattern signal generator
- Photo Research SpectraScan PR-650 spectroradiometer
- Photo Research SpectraScan PR-704 spectroradiometer
- Minolta LS-100 Photometer
- Minolta CA-100 Colorimeter
- Graseby S370 Illuminance Meter
- Microvision Superspot 100 Display Characterization System which included OM-1 optic module (Two Dimensional photodiode linear array device, projected element size at screen set to 1.3 mils with photopic filter) and.Spotseeker 4-Axis Positioner

Stereoscopic-mode measurements were made using the following commercially-available stereo products:

- Stereographics Z-Screen 19-inch LCD shutter with passive polarized eyeglasses.
- Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Section II PHOTOMETRIC MEASUREMENTS

II.1. Dynamic range and Screen Reflectance

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.*

VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 199, Section 308-1.

Full screen white-to-black contrast ratio measured in 1600 x 1200 format is 367:1 (25.6 dB dynamic range) in a dark room. It decreases to under 158:1 (22 dB), the absolute threshold for IEC, in 2 fc diffuse ambient illumination.

Objective: Measure the photometric output (luminance vs. input command level) at Lmax and Lmin in both dark room and illuminated ambient conditions.

Equipment: Photometer, Integrating Hemisphere Light Source or equivalent

Procedure: Luminance at center of screen is measured for input counts of 0 and Max Count. Test targets are full screen (flat fields) where full screen is defined addressability. Set Lmin to 0.1 fL. For color monitors, set color temperature between D_{65} to D_{93} . Measure Lmax.

This procedure applies when intended ambient light level measured at the display is 2fc or less. For conditions of higher ambient light level, Lmin and Lmax should be measured at some nominal intended ambient light level (e.g., 18-20 fc for normal office lighting with no shielding). This requires use of a remote spot photometer following procedures outlined in reference 2, paragraph 308-2. This will at best be only an approximation since specular reflections will not be captured. A Lmin > 0.1 fL may be required to meet grayscale visibility requirements.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are silmutaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in figure II.1-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by an integrating hemisphere simulated using a polystyrene ice box. Luminance is measured using a spot photometer with 1° measurement field and an illuminance sensor as depicted in Figure II.1-1. The measured values and calculated reflectances are given in Table II.1-1.

Data: Contrast ratio is a linear expression of Lmax to Lmin. Dynamic range expresses the contrast ratio in log units, dB, which correlates more closely with the sensitivity of the human vision system.

Define contrast ratio by: CR = Lmax/Lmin

Define dynamic range by: DR = 10log(Lmax/Lmin)

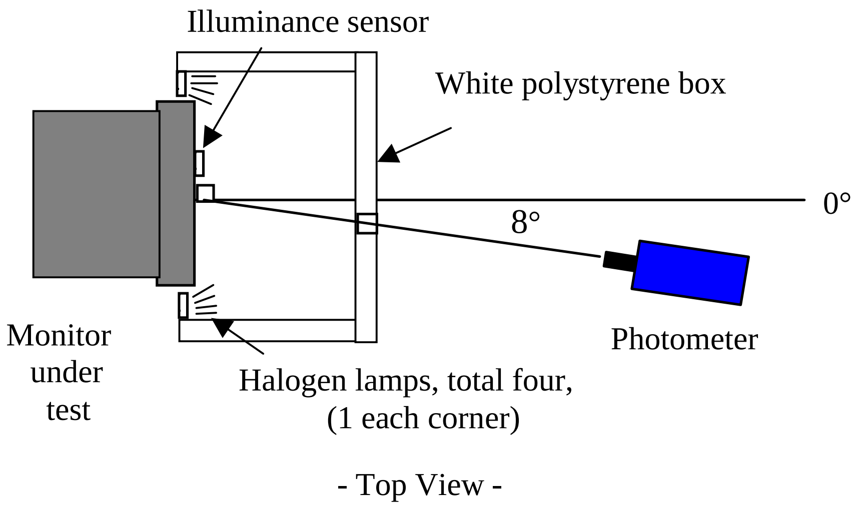


Figure II.1-1. Test setup according to VESA FPDM procedures for measuring total reflectance of screen.

Table II.1-1. Directed Hemispherical Reflectance of Faceplate
VESA ambient contrast illuminance source (polystyrene box)

Ambient Illuminance	20.08 fc
Reflected Luminance	1.623 fL
Faceplate Reflectance	8.1 %

Ambient dynamic ranges of full screen white-to-black given in Table II.1-2 were computed for various levels of diffuse ambient lighting using the measured value for DHR and the darkroom dynamic range measurements. Full screen white-to-black decreases from 367:1 (25.6 dB dynamic range) in a dark room to less than 22 dB (the absolute threshold for IEC) in 2 fc diffuse ambient illumination.

Table II.1-2.Dynamic Range in Dark and Illuminated Rooms

Effect of ambient lighting on dynamic range is calculated by multiplying the measured CRT faceplate reflectivity times the ambient illumination measured at the CRT in foot candles added to the minimum screen luminance, Lmin, where Lmin = 0.1 fL.

Ambient Illumination	Contrast Ratio	Dynamic Range
0 fc (Dark Room)	367 :1	25.6 dB
1 fc	203 :1	23.1 dB
2 fc	141 :1	21.5 dB
3 fc	108 :1	20.3 dB
4 fc	87 :1	19.4 dB
5 fc	74 :1	18.7 dB
6 fc	64 :1	18.0 dB
7 fc	56 :1	17.5 dB
8 fc	50 :1	17.0 dB
9 fc	45 :1	16.6 dB
10 fc	41 :1	16.2 dB
11 fc	38 :1	15.8 dB
12 fc	35 :1	15.5 dB
13 fc	33 :1	15.2 dB
14 fc	31 :1	14.9 dB
15 fc	29 :1	14.6 dB

II.2. Maximum Luminance (Lmax)

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.2, p 6.*

The monitor was tested with luminance for Lmax set to 36.7 fL measured at screen center in 1600 x 1200 monoscopic format. The absolute maximum full screen monoscopic luminance was 164fL with the contrast control at the maximum setting and Lmin set to 0.1 fL.

Objective: Measure the maximum output display luminance.

Equipment: Photometer

Procedure: See dynamic range. Use the value of Lmax defined for the Dynamic Range measurement.

Data: The maximum output display luminance, Lmax, and associated CIE x, y chromaticity coordinates (CIE 1976) were measured using a hand-held colorimeter (Minolta CA-100).

Table II.2-1. Maximum Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at screen center.

Format	CCT	CIE x	CIE y	Luminance
1600 x 1200	11466 K	0.252	0.311	36.7

II.3. Luminance (Lmax) and Color Uniformity

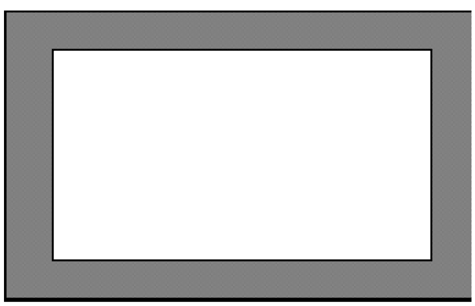
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

Maximum luminance (Lmax) varied by up to 13.9% across the screen. Chromaticity variations were less than 0.0023 delta u'v' units.

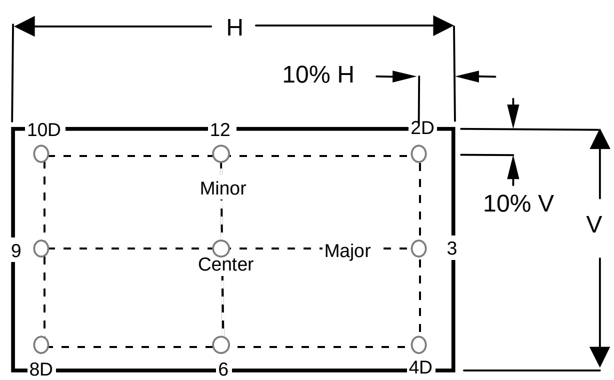
Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% Lmax only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

Equipment:
- Video generator
- Photometer
- Spectroradiometer or Colorimeter

Test Pattern: Full screen flat field with visible edges at L_{min} as shown in Figure II.3-1.



Full Screen Flat Field test pattern.
Figure II.3-1



Nine screen test locations.
Figure II.3-2

Procedure: Investigate the temporal variation of luminance and the white point as a function of intensity by displaying a full flat field shown in Figure II.3-1 for video input count levels corresponding L_{max}. Measure the luminance and C.I.E. color coordinates at center screen.

Investigate the temporal variation of luminance and the white point as a function of spatial position by repeating these measurements at each of the locations depicted in Figure II.3-2. Define color uniformity in terms of Δ u´v´.

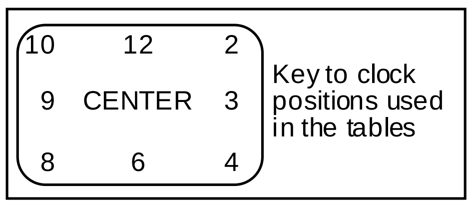
Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Table II.3-1.Spatial Uniformity of Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at nine screen positions.

1600 x 1200

POSITION	CCT, K	CIE x	CIE y	L, fL
center	11466	0.252	0.311	36.7
2	11596	0.250	0.312	33.5
3	11381	0.251	0.314	32.1
4	11440	0.251	0.313	32.4
6	11288	0.252	0.314	36.2
8	11689	0.251	0.309	32.6
9	11722	0.250	0.310	32.3
10	11854	0.250	0.308	33.2
12	11562	0.251	0.311	37.3



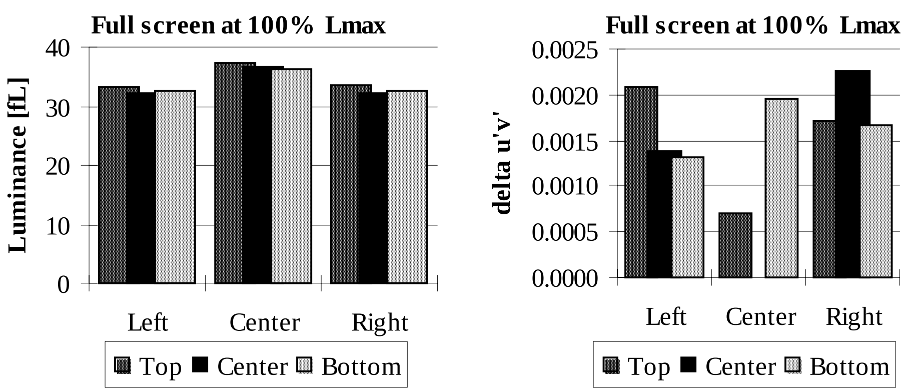


Fig.II.3-3. Spatial Uniformity of Luminance and Chromaticity.
(Delta u'v' of 0.004 is just visible.)

II.4. Halation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 48.

Halation was 3.89% +/- 0.3% on a small black patch surrounded by a large full white area.

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. The mechanisms that give rise to halation, and its detailed non-monotonic dependence on the distance along the screen between the source of illumination and the region being measured have been described by E. B. Gindele and S.L. Shaffer. The measurements specified below determine the percentage of light that is piped into the dark areas as a function of the extent of the surrounding light areas.

Equipment:
- Photometer
- Video generator

Test Pattern:

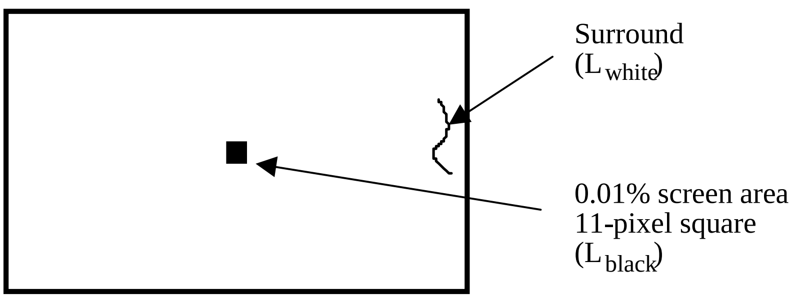


Figure II.4-1 *Test pattern for measuring halation.*

Procedure: Note: The halation measurements require changing the setting of the BRIGHTNESS control and will perturb the values of L_{max} and L_{min} that are established during the initial monitor set-up. The halation measurements should therefore be made either first, before the monitor setup, or last, after all other photometric measurements have been completed.

Determine halation by measuring the luminance of a small square displayed at L_{black} (essentially zero) and at L_{white} when surrounded by a much larger square displayed at L_{white} (approximately 75% L_{max}).

Establish L_{black} by setting the display to cutoff. To set the display to cut-off, display a flat field using video input count level zero, and use a photometer to monitor the luminance at center screen. Vary the BRIGHTNESS control until the CRT beam is visually cut off, and confirm that the corresponding luminance (L_{stray}) is essentially equal to zero. Fine tune the BRIGHTNESS control such that CRT beam is just on the verge of being cut off. These measurements should be made with a photometer which is sensitive at low light levels (below L_{min} of the display). Make no further adjustments or changes to the BRIGHTNESS control or the photometer measurement field.

Next, decrease the video input level to display a measured full-screen luminance of 75% L_{max} measured at screen center. Record this luminance (L_{white}).

The test target used in the halation measurements is a black (L_{black}) square patch of width equal to 0.01% of the area of addressable screen, the interior square as shown in Figure II.4-1. The interior square patch is enclosed in a white (L_{white}) background encompassing the remaining area of the image. The exterior surround will be displayed at 75% L_{max} using the input count level for L_{white} as determined above. The interior square will be displayed at input digital count level zero.

Care must be taken during the luminance measurement to ensure that the photometer's measurement field is less than one-half the size of the interior square and is accurately positioned not to extend beyond the boundary of the interior square. The photometer should be checked for light scattering or lens flare effects which allow light from the surround to enter the photosensor. A black card with aperture equal to the measurement field (one-half the size of the interior black square) may be used to shield the photometer from the white exterior square while making measurements in the interior black square.

Analysis: Compute the percent halation for each test target configuration. Percent halation is defined as:

$$\%\ \text{Halation} = L_{black} \ / \ (L_{white} - L_{black}) \quad \times 100$$

Where, L_{black} = measured luminance of interior square displayed at L_{black} using input count level zero,

L_{white} = measured luminance of interior square displayed at L_{white} using input count level determined to produce a full screen luminance of 75% L_{max} .

Data: Table II.4-1 contains measured values of L_{black}, L_{white} and percentage halation.

Table II.4-1 Halation for 1600 x 1200 Addressability

Note: Lmin was not set to cutoff. Instead, Lmin is subtracted from Lblack and Lwhite for calculating the halation.

	Reported Values	Range for 4% uncertainty
Lmin	0.071	0.0682 fL to 0.0738 fL
Lblack	1.18 fL ± 4%	1.14 fL to 1.23 fL
Lwhite	28.7 fL ± 4%	27.6 fL to 29.8 fL
Halation	3.89% ± 0.3%	3.57% to 4.24%

II.5. Color Temperature

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 5.4, page 22.

The CCT of the measured white point is 11466 K and is not specified for monochrome monitors for IEC.

II.6. Bit Depth

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.

Positive increases in luminance were measured for each of the 256 input levels for 8 bits of gray scale. No black level clipping nor white level saturation were observed. Cyclic automatic corrections in the monitor produced up to 0.007 fL variation in luminance (7% Lmin) even after the initial warm up period.

Objective: Measure the number of bits of data that can be displayed as a function of the DAC and display software.

Equipment: Photometer

Test targets: Targets are n four inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels.

Procedure: Measure patch center for all patches with Lmin and Lmax as defined previously. Count number of monotonically increasing luminance levels. Use the NEMA/DICOM model to define discriminable luminance differences. For color displays, measure white values.

Data: Define bit depth by $\log_2$ (number of discrete luminance levels)

The number of bits of data that can be displayed as a function of the input signal voltage level were verified through measurements of the luminance of white test targets displayed using a Quantum Data 8701 test pattern generator and a Minolta CA-100 colorimeter. Targets are n four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels. The NEMA/DICOM model was used to define discriminable luminance differences in JNDs.

Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2.

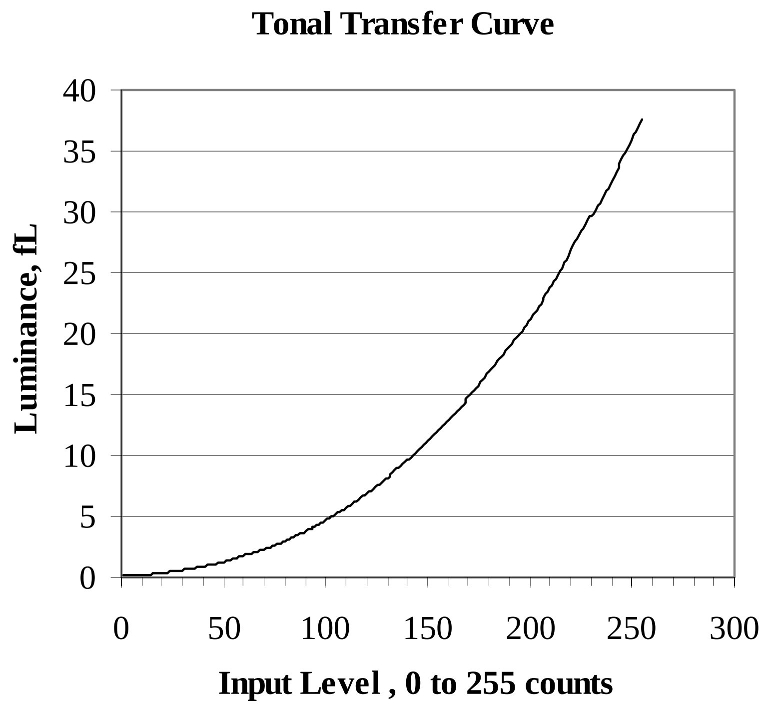


Figure II.6-1. System Tonal Transfer at center screen as a function of input counts.

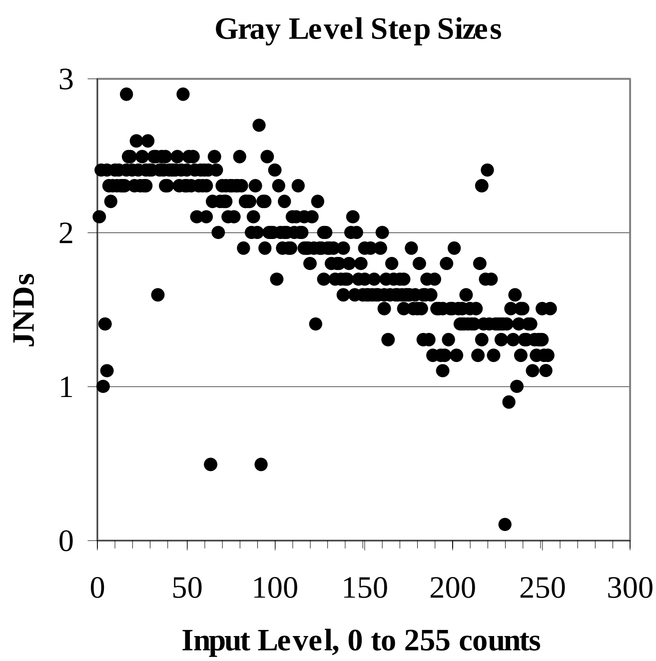


Figure II.6-2. Perceptibility of gray level steps at center screen as a function of input counts.

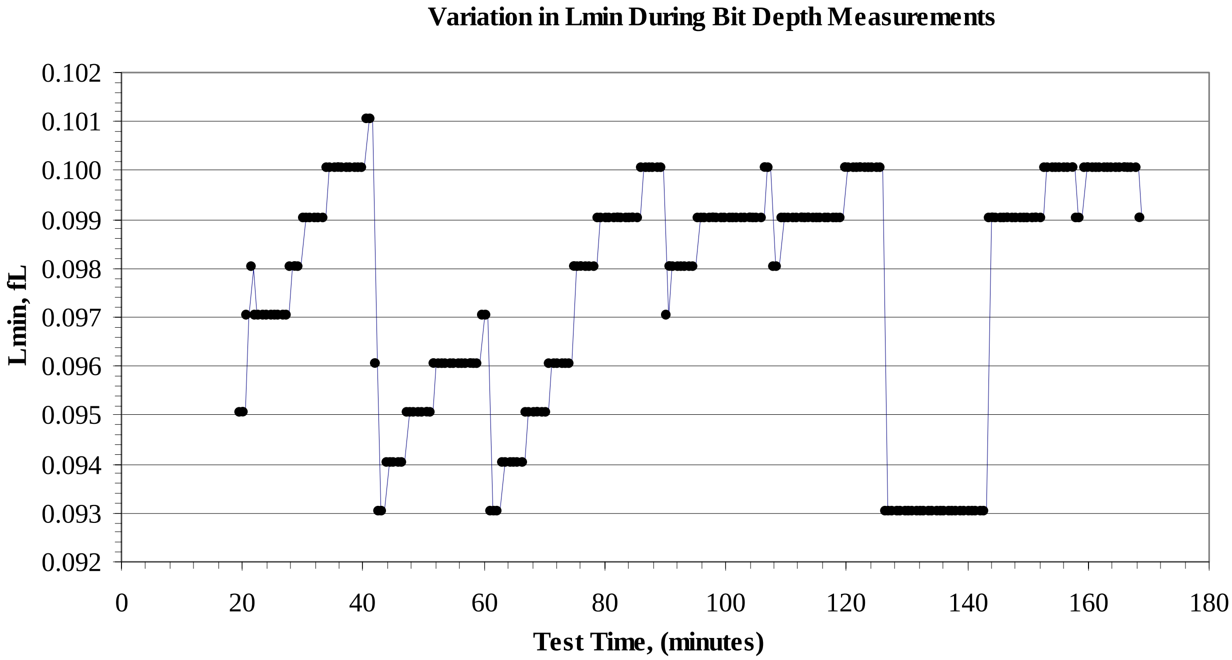


Figure II.6-3. Cyclic automatic corrections in the monitor produced variations in screen luminance of up to 0.008 fL (8% Lmin) which continued for several hours beyond the initial warm up period. While this variation is within the 10% Lmin luminance requirement for IEC warm up time, this slight luminance instability is roughly equal to a luminance step size between dark gray levels and so, was enough to perturb the sequential measurement of 256 gray levels for the evaluation of bit depth (see Section II.6 Bit Depth).

Table II.6-1. System Tonal Transfer at center screen as a function of input counts 000 to 127.

Background	Target	L, fL	Diff, fL	Diff, JND
38	0	0.103	0	0.0
39	1	0.111	0.008	2.1
39	2	0.121	0.01	2.4
39	3	0.125	0.004	1.0
40	4	0.131	0.006	1.4
40	5	0.136	0.005	1.1
41	6	0.147	0.011	2.4
41	7	0.158	0.011	2.3
41	8	0.169	0.011	2.2
42	9	0.181	0.012	2.3
42	10	0.194	0.013	2.4
42	11	0.207	0.013	2.3
43	12	0.221	0.014	2.4
43	13	0.235	0.014	2.3
43	14	0.25	0.015	2.3
44	15	0.265	0.015	2.3
44	16	0.285	0.02	2.9
44	17	0.302	0.017	2.4
45	18	0.32	0.018	2.5
45	19	0.339	0.019	2.5
45	20	0.358	0.019	2.4
46	21	0.377	0.019	2.3
46	22	0.399	0.022	2.6
46	23	0.42	0.021	2.4
47	24	0.441	0.021	2.3
47	25	0.464	0.023	2.5
48	26	0.486	0.022	2.3
48	27	0.51	0.024	2.4
48	28	0.534	0.024	2.3
49	29	0.561	0.027	2.6
49	30	0.587	0.026	2.4
49	31	0.614	0.027	2.4
50	32	0.643	0.029	2.5
50	33	0.672	0.029	2.5
50	34	0.692	0.02	1.6
51	35	0.722	0.03	2.4
51	36	0.753	0.031	2.5
51	37	0.785	0.032	2.4
52	38	0.816	0.031	2.3
52	39	0.85	0.034	2.5
52	40	0.883	0.033	2.3
53	41	0.918	0.035	2.4
53	42	0.954	0.036	2.4
53	43	0.991	0.037	2.4
54	44	1.029	0.038	2.4
54	45	1.068	0.039	2.5
55	46	1.107	0.039	2.3
55	47	1.148	0.041	2.4
55	48	1.197	0.049	2.9
56	49	1.239	0.042	2.3
56	50	1.282	0.043	2.4
56	51	1.326	0.044	2.3
57	52	1.373	0.047	2.5
57	53	1.418	0.045	2.3
57	54	1.468	0.05	2.5
58	55	1.517	0.049	2.4
58	56	1.562	0.045	2.1
58	57	1.612	0.05	2.3
59	58	1.664	0.052	2.4
59	59	1.716	0.052	2.3
59	60	1.77	0.054	2.4
60	61	1.823	0.053	2.3
60	62	1.874	0.051	2.1
60	63	1.933	0.059	2.4
61	64	1.945	0.012	0.5
61	65	1.999	0.054	2.2
62	66	2.062	0.063	2.5
62	67	2.124	0.062	2.4
62	68	2.178	0.054	2.0
63	69	2.238	0.06	2.2
63	70	2.302	0.064	2.3
63	71	2.364	0.062	2.2
64	72	2.427	0.063	2.2
64	73	2.492	0.065	2.3
64	74	2.556	0.064	2.1
65	75	2.627	0.071	2.3
65	76	2.697	0.07	2.3
65	77	2.762	0.065	2.1
66	78	2.836	0.074	2.3
66	79	2.912	0.076	2.3
66	80	2.997	0.085	2.5
67	81	3.073	0.076	2.3
67	82	3.141	0.068	1.9
67	83	3.216	0.075	2.2
68	84	3.295	0.079	2.2
68	85	3.377	0.082	2.2
69	86	3.459	0.082	2.2
69	87	3.535	0.076	2.0
69	88	3.616	0.081	2.1
70	89	3.704	0.088	2.3
70	90	3.786	0.082	2.0
70	91	3.896	0.11	2.7
71	92	3.917	0.021	0.5
71	93	4.008	0.091	2.2
71	94	4.098	0.09	2.2
72	95	4.182	0.084	1.9
72	96	4.293	0.111	2.5
72	97	4.381	0.088	2.0
73	98	4.471	0.09	2.0
73	99	4.565	0.094	2.0
73	100	4.673	0.108	2.4
74	101	4.754	0.081	1.7
74	102	4.868	0.114	2.3
74	103	4.965	0.097	2.0
75	104	5.058	0.093	1.9
75	105	5.169	0.111	2.2
76	106	5.274	0.105	2.0
76	107	5.376	0.102	2.0
76	108	5.481	0.105	1.9
77	109	5.583	0.102	1.9
77	110	5.697	0.114	2.1
77	111	5.808	0.111	2.0
78	112	5.927	0.119	2.1
78	113	6.056	0.129	2.3
78	114	6.176	0.12	2.0
79	115	6.293	0.117	2.0
79	116	6.407	0.114	1.9
79	117	6.535	0.128	2.1
80	118	6.649	0.114	1.9
80	119	6.771	0.122	1.9
80	120	6.885	0.114	1.8
81	121	7.022	0.137	2.1
81	122	7.142	0.12	1.9
81	123	7.237	0.095	1.4
82	124	7.387	0.15	2.2
82	125	7.516	0.129	1.9
83	126	7.647	0.131	1.9
83	127	7.787	0.14	2.0

Table II.6-2. System Tonal Transfer at center screen as a function of input counts 128 to 255.

Background	Target	L, fL	Diff, fL	Diff, JND
83	128	7.904	0.117	1.7
84	129	8.047	0.143	2.0
84	130	8.187	0.14	1.9
84	131	8.327	0.14	1.9
85	132	8.464	0.137	1.8
85	133	8.607	0.143	1.9
85	134	8.744	0.137	1.7
86	135	8.884	0.14	1.8
86	136	9.027	0.143	1.8
86	137	9.158	0.131	1.7
87	138	9.293	0.135	1.6
87	139	9.448	0.155	1.9
87	140	9.584	0.136	1.7
88	141	9.73	0.146	1.7
88	142	9.884	0.154	1.8
88	143	10.06	0.176	2.0
89	144	10.24	0.18	2.1
89	145	10.38	0.14	1.6
90	146	10.56	0.18	2.0
90	147	10.72	0.16	1.7
90	148	10.88	0.16	1.8
91	149	11.03	0.15	1.6
91	150	11.21	0.18	1.9
91	151	11.38	0.17	1.7
92	152	11.53	0.15	1.6
92	153	11.69	0.16	1.6
92	154	11.88	0.19	1.9
93	155	12.04	0.16	1.6
93	156	12.21	0.17	1.7
93	157	12.37	0.16	1.6
94	158	12.54	0.17	1.6
94	159	12.74	0.2	1.9
94	160	12.95	0.21	2.0
95	161	13.12	0.17	1.5
95	162	13.29	0.17	1.6
95	163	13.48	0.19	1.7
96	164	13.62	0.14	1.3
96	165	13.81	0.19	1.6
97	166	14.01	0.2	1.8
97	167	14.21	0.2	1.7
97	168	14.39	0.18	1.6
98	169	14.58	0.19	1.6
98	170	14.79	0.21	1.7
98	171	14.98	0.19	1.6
99	172	15.19	0.21	1.7
99	173	15.37	0.18	1.5
99	174	15.57	0.2	1.6
100	175	15.77	0.2	1.6
100	176	15.98	0.21	1.6
100	177	16.22	0.24	1.9
101	178	16.42	0.2	1.5
101	179	16.64	0.22	1.6
101	180	16.83	0.19	1.5
102	181	17.08	0.25	1.8
102	182	17.28	0.2	1.5
102	183	17.5	0.22	1.6
103	184	17.68	0.18	1.3
103	185	17.91	0.23	1.6
104	186	18.16	0.25	1.7
104	187	18.34	0.18	1.3
104	188	18.57	0.23	1.6
105	189	18.75	0.18	1.2
105	190	19	0.25	1.7
105	191	19.22	0.22	1.5
106	192	19.45	0.23	1.5
106	193	19.64	0.19	1.2
106	194	19.81	0.17	1.1
107	195	20.04	0.23	1.5
107	196	20.23	0.19	1.2
107	197	20.51	0.28	1.8
108	198	20.72	0.21	1.3
108	199	20.96	0.24	1.5
108	200	21.21	0.25	1.5
109	201	21.52	0.31	1.9
109	202	21.72	0.2	1.2
109	203	21.98	0.26	1.5
110	204	22.21	0.23	1.4
110	205	22.46	0.25	1.4
111	206	22.71	0.25	1.5
111	207	22.96	0.25	1.4
111	208	23.25	0.29	1.6
112	209	23.49	0.24	1.4
112	210	23.77	0.28	1.5
112	211	24.03	0.26	1.4
113	212	24.28	0.25	1.4
113	213	24.56	0.28	1.5
113	214	24.78	0.22	1.2
114	215	25.12	0.34	1.8
114	216	25.38	0.26	1.3
114	217	25.81	0.43	2.3
115	218	26.09	0.28	1.4
115	219	26.43	0.34	1.7
115	220	26.91	0.48	2.4
116	221	27.19	0.28	1.4
116	222	27.54	0.35	1.7
116	223	27.8	0.26	1.2
117	224	28.1	0.3	1.4
117	225	28.38	0.28	1.4
118	226	28.68	0.3	1.4
118	227	28.96	0.28	1.3
118	228	29.27	0.31	1.4
119	229	29.57	0.3	1.4
119	230	29.6	0.03	0.1
119	231	29.9	0.3	1.4
120	232	30.12	0.22	0.9
120	233	30.45	0.33	1.5
120	234	30.75	0.3	1.3
121	235	31.1	0.35	1.6
121	236	31.34	0.24	1.0
121	237	31.67	0.33	1.4
122	238	31.96	0.29	1.2
122	239	32.3	0.34	1.5
122	240	32.66	0.36	1.5
123	241	32.98	0.32	1.3
123	242	33.3	0.32	1.3
123	243	33.65	0.35	1.4
124	244	33.99	0.34	1.4
124	245	34.27	0.28	1.1
125	246	34.59	0.32	1.3
125	247	34.91	0.32	1.2
125	248	35.24	0.33	1.3
126	249	35.56	0.32	1.3
126	250	35.92	0.36	1.3
126	251	36.31	0.39	1.5
127	252	36.62	0.31	1.2
127	253	36.92	0.3	1.1
127	254	37.24	0.32	1.2
128	255	37.65	0.41	1.5

II.8. Luminance Step Response

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.8, p 7.

No artifacts were observed in the SMPTE test pattern.

Objective: Determine the presence of artifacts caused by undershoot or overshoot.

Equipment: Test targets, SMPTE Test Pattern RP-133-1991, 2-D CCD array

Procedure: Display a center box 15% of screen size at input count levels corresponding to 25%, 50%, 75%, and 100% of Lmax with a surround of count level 0. Repeat using SMPTE Test pattern

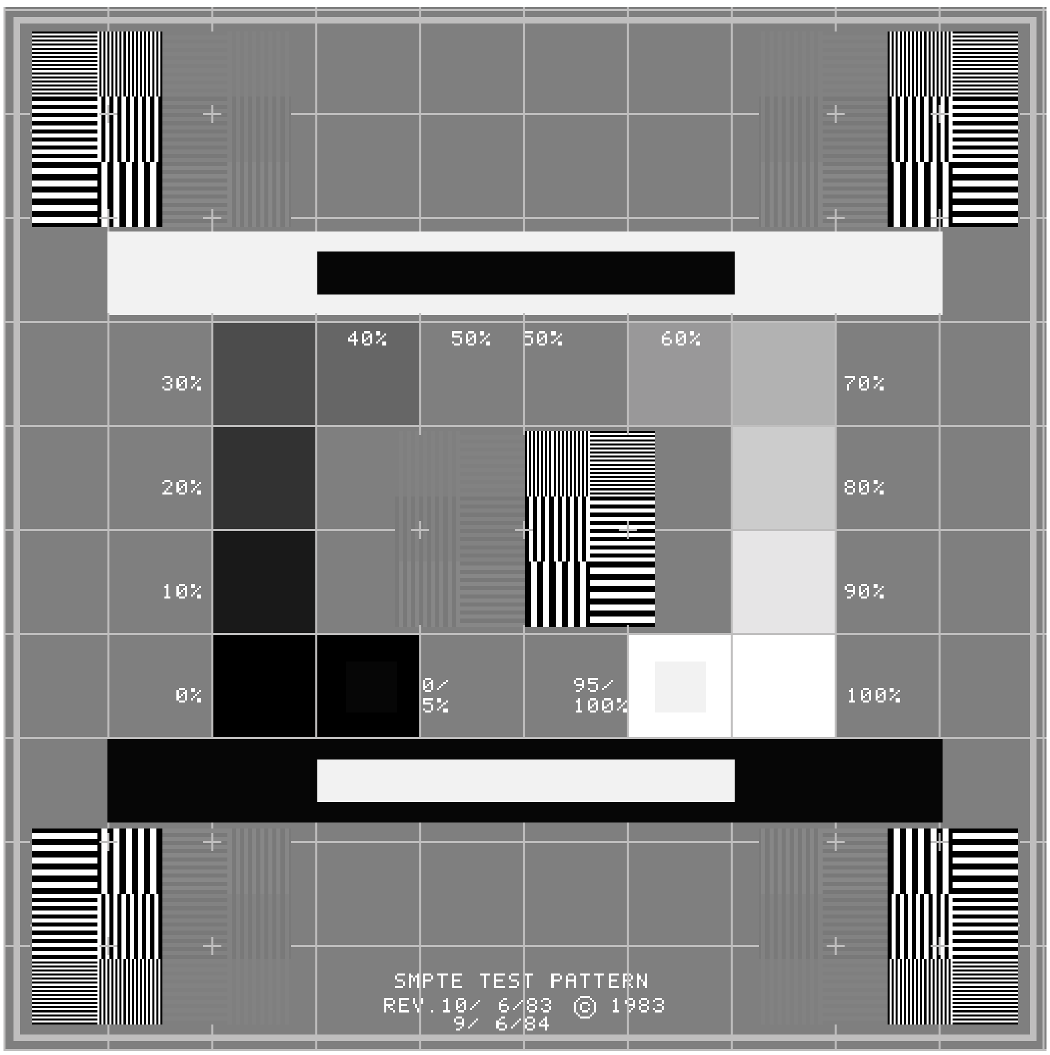


Figure II.8-1. SMPTE Test Pattern .

Data: Define pass by absence of noticeable ringing, undershoot, overshoot, or streaking. The test pattern shown in Figure II.8-1 was used in the visual evaluation of the monitor. This test pattern is defined in SMPTE Recommended Practice RP-133-1986 published by the Society of Motion Picture and Television Engineers (SMPTE) for medical imaging applications. Referring to the large white-in-black and black-in-white horizontal bars contained in the test pattern, RP133-1986, paragraph 2.7 states " These areas of maximum contrast facilitate detection of mid-band streaking (poor low-frequency response), video amplifier ringing or overshoot, deflection interference, and halo." None of these artifacts were observed in the Data-Ray DR96L monitor, signifying good electrical performance of the video circuits.

II.9. Addressability

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1, page 67.

This monitor properly displayed all addressed pixels for the following tested formats (HxV): 1600 x 1200x 72 Hz, and 1024 x 1024 x 120 Hz.

Objective: Define the number of addressable pixels in the horizontal and vertical dimension; confirm that stated number of pixels is displayed.

Equipment: Programmable video signal generator.
Test pattern with pixels lit on first and last addressable rows and columns and on two diagonal lines beginning at upper left and lower right; H & V grill patterns 1-on/1-off.

Procedure: The number of addressed pixels were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible. All perimeter lines were confirmed to be visible, with no irregular jaggies on diagonals and, for monochrome monitors, no strongly visible moiré on grilles.

Data: If tests passed, number of pixels in horizontal and vertical dimension. If test fails, addressability unknown.

Table II.9-1 Addressabilities Tested

Monoscopic Mode	Stereo Mode
1600 x 1200 x 72Hz	1024 x 1024 x 120Hz

II.10. Pixel Aspect Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.10, p 8.

Pixel aspect ratio was set to 1:1 (H = V + 0.0%).

Objective: Characterize aspect ratio of pixels.

Equipment: Test target, measuring tape with at least 1/16th inch increments

Procedure: Display box of 400 x 400 pixels at input count corresponding to 50% Lmax and background of 0. Measure horizontal and vertical dimension.

Alternatively, divide number of addressable pixels by the total image size to obtain nominal pixel spacings in horizontal and vertical directions.

Data: Define pass if H= V± 6% for pixel density <100 ppi and ± 10% for pixel density > 100 ppi.

	Monoscopic Mode
Addressability (H x V)	1600 x 1200
H x V Image Size (inches)	15.50 x 11.625
H x V Pixel Spacing (mils)	9.69 x 9.69 mils
H x V Pixel Aspect Ratio	H = V + 0.0%

II.11. Screen Size (Viewable Active Image)

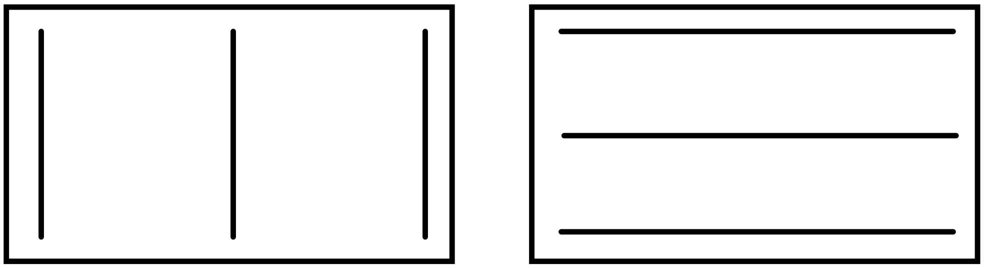
Reference: VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998, Section 501-1.

Image size as tested was 19.375 inches in diagonal.

Objective: Measure beam position on the CRT display to quantify width and height of active image size visible by the user (excludes any over-scanned portion of an image).

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.11-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.11-1 Three-line grille test patterns.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x,y coordinates of lines at the ends of the major and minor axes.

Data: Compute the image width defined as the average length of the horizontal lines along the top, bottom and major axis of the screen. Similarly, compute the image height defined as the average length of the vertical lines along the left side, right side, and minor axis of the screen. Compute the diagonal screen size as the square-root of the sum of the squares of the width and height.

Table II.11-1. Image Size

	Monoscopic Mode
Addressability (H x V)	1600 x 1200
H x V Image Size (inches) Diagonal Image Size (inches)	15.50 x 11.625 19.375

II.12. Contrast Modulation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 5.2, page 57.

Contrast modulation (Cm) for 1-on/1-off grille patterns displayed at 50% Lmax exceeded Cm = 23% in Zone A, and exceeded Cm = 13% in Zone B.

Objective: Quantify contrast modulation as a function of screen position.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Photometer with linearized response

Procedure: The maximum video modulation frequency for each 1600 x 1200 format was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. Contrast modulation was measured in both horizontal and vertical directions at screen center and at eight peripheral screen positions. The measurements should be along the horizontal and vertical axes and along the diagonal from these axes. Use edge measurements no more than 10% of screen size in from border of active screen. The input signal level was set so that 1-line-on/1-line-off horizontal grille patterns produced a screen area-luminance of 25% of maximum level, Lmax..

Zone A is defined as a 24 degree subtense circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define Cm for Zone B (remaining area outside center circle). Determine Cm at eight points on circumference of circle by interpolating between center and display edge measurements to define Cm for Zone A. If measurements exceed the threshold, do not make any more measurements. If one or more measurements fail the threshold, make eight additional measurements at the edge (but wholly within) the defined circle.

Data: Values of vertical and horizontal Cm for Zone A and Zone B are given in Table II.12-1. The contrast modulation, Cm, is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation is equal to or greater than 23% in Zone A, and is equal to or greater than 13% in Zone B.

$$C_m = \frac{L_{peak} - L_{valley}}{L_{peak} + L_{valley}}$$

Table II.12-1. Contrast Modulation

Corrected for lens flare and Zone Interpolation

Zone A 7.6-inch diameter circle for 24-degree subtense at 18-inch viewing distance

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	23%	31%			23%	51%			72%	22%
			52%	32%	40%	44%	71%	28%		
Major	35%	13%	53%	23%	71%	32%	74%	27%	77%	23%
			59%	25%	45%	39%	70%	32%		
Bottom	40%	14%			31%	43%			69%	32%

Zone A 9.58-inch diameter circle for 40% area

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	23%	31%			23%	51%			72%	22%
			51%	33%	32%	48%	75%	29%		
Major	35%	13%	51%	21%	77%	35%	77%	27%	77%	23%
			59%	24%	39%	42%	73%	33%		
Bottom	40%	14%			31%	43%			69%	32%

II.13. Pixel Density

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.13, p 9.

Pixel density was set to 103 ppi for the 1600 x 1200-line addressable format.

Objective: Characterize density of image pixels

Equipment: Measuring tape with at least 1/16 inch increments

Procedure: Measure H&V dimension of active image window and divide by vertical and horizontal addressability

Data: Define horizontal and vertical pixel density in terms of pixels per inch

Table II.13-1. Pixel-Density

	Monoscopic Mode
Addressability (H x V)	1600 x 1200
H x V Image Size (inches)	15.50 x 11.625
H x V Pixel Density, ppi	103 x 103

II.14. Moire

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.14, p 9.

Not applicable to monochrome monitors.

II.15. Straightness

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

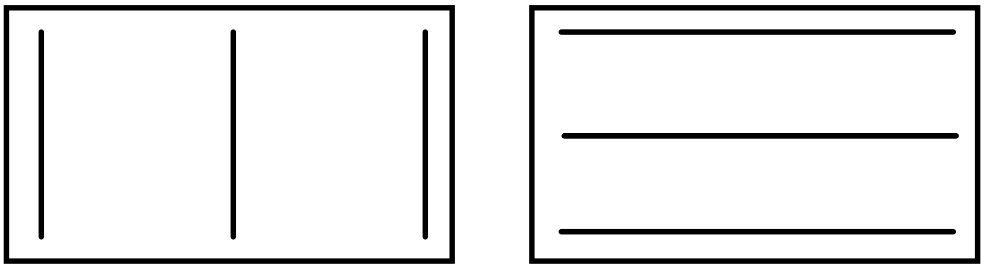
Pincushion of 0.82% along the bottom of the screen exceeded the maximum distortion allowed by IEC (0.5% max.).

Objective: Measure beam position on the CRT display to quantify effects of waviness which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module

• Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.15-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.15-1 Three-line grille test patterns.

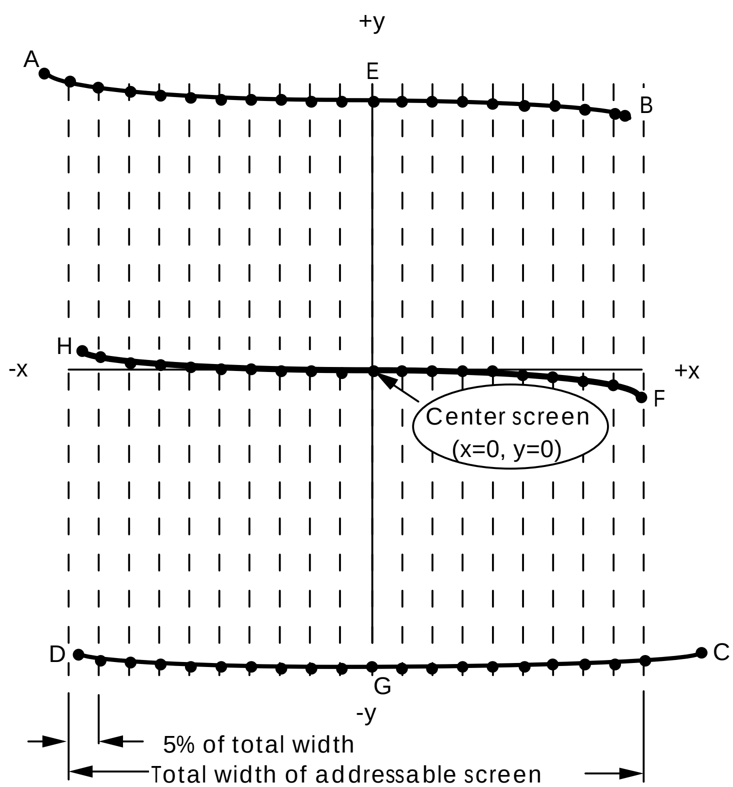


Figure II.15-2 Measurement locations for waviness along horizontal lines. Points A, B, C, D are extreme corner points of addressable screen. Points E, F, G, H are the endpoints of the axes.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x,y coordinates along the length of a nominally straight line. Measure x,y coordinates at 5% addressable screen intervals along the line. Position vertical lines in video to land at each of three (3) horizontal screen locations for determining waviness in the horizontal direction. Similarly, position horizontal lines in video to land at each of three (3) vertical screen locations for determining waviness in the vertical direction.

Data: Tabulate x,y positions at 5% addressable screen increments along nominally straight lines at top and bottom, major and minor axes, and left and right sides of the screen as shown in Table II.15-I. Figure II.15-3 shows the results in graphical form.

Table II.15-1. Pincushion

Top		Bottom		Left Side		Right Side	
0.34%		0.82%		0.35%		0.19%	
Tabulated x,y positions in mils along nominally straight lines.							
x	y	x	y	x	y	x	y
-7846	5747	-7741	-5884	-7846	5747	7685	5800
0	5783	0	-5785	-7802	0	7673	0
7685	5800	7622	-5857	-7741	-5884	7622	-5857

II.16. Refresh Rate

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.16, p 9.

Vertical refresh rate for the1600 x 1200 format was set to 72 Hz. Vertical refresh rate for the 1024 x 1024 stereo format was set to 120 Hz.

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible.

Data: Report refresh rates in Hz.

Table II.16-1 Refresh Rates as Tested

	Monoscopic Mode	Stereo Mode *
Addressability	1600 x 1200	1024 x 1024
Vertical Scan Horizontal Scan	72 Hz 89.3 kHz	120 Hz 126.8 kHz

* Note: Stereo refresh rate as high as 122 Hz at 128.9 kHz horizontal scan rate was verified by NIDL.

II.17. Extinction Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio was averaged 28.4 to 1 (33.3 left, 23.5 right) at screen center.

Objective: Measure stereo extinction ratio

Equipment: Two "stereo" pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially-available Stereographics Z Screen 19-inch LCD shutter with passive polarized eyeglasses.

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient). Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L(left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

Stereo extinction ratio is average of left and right ratios defined above.

Table II.17-1 Extinction Ratio

		Left Eye	Right Eye	Avg. Left, Right
Lmin, fL to the eye,	Black/Black	0.81	0.93	0.87
Lmax, fL to the eye,	White/White	30.0	35.0	32.5
	White/Black	29.7	1.44	15.5
	Black/White	0.89	33.9	17.4
	Extinction Ratio	**33.3**	**23.5**	**28.4**

II.18. Linearity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.2, page 73.

The maximum nonlinearity of the scan was 1.88 % of full screen.

Objective: Measure the relation between the actual position of a pixel on the screen and the commanded position to quantify effects of raster nonlinearity. Nonlinearity of scan degrades the preservation of scale in images across the display.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use grille patterns of single-pixel horizontal lines and single-pixel vertical lines displayed at 100% L_{max}. Lines are equally spaced in addressable pixels. Spacing must be constant and equal to approximately 5% screen width and height to the nearest addressable pixel as shown in Figure II.18-1.

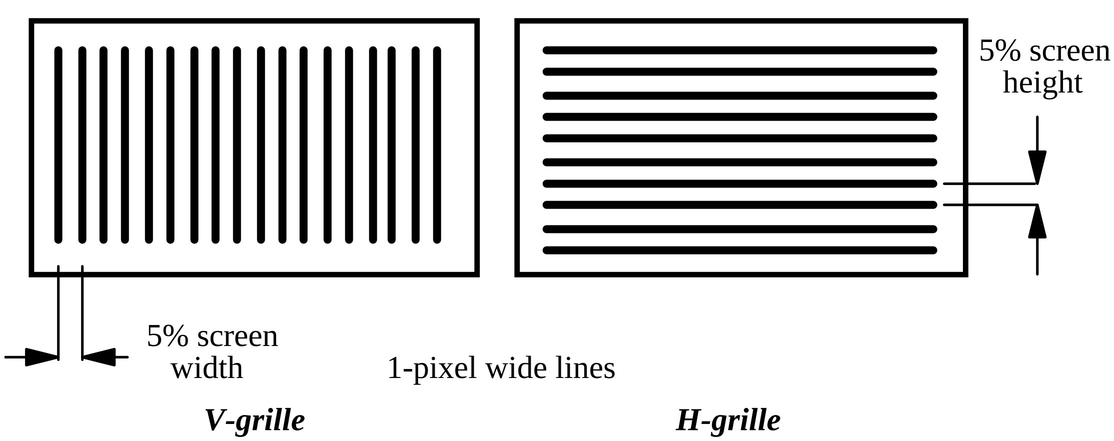


Figure II.18-1. *Grille patterns for measuring linearity*

Procedure: The linearity of the raster scan is determined by measuring the positions of lines on the screen. Vertical lines are measured for the horizontal scan, and horizontal lines for the vertical scan. Lines are commanded to 100% Lmax and are equally spaced in the time domain by pixel indexing on the video test pattern. Use optic module to locate center of line profiles in conjunction with x,y-translation stage to measure screen x,y coordinates of points where video pattern vertical lines intersect horizontal centerline of screen and where horizontal lines intersect vertical centerline of the CRT screen as shown in Figure II.18-2.

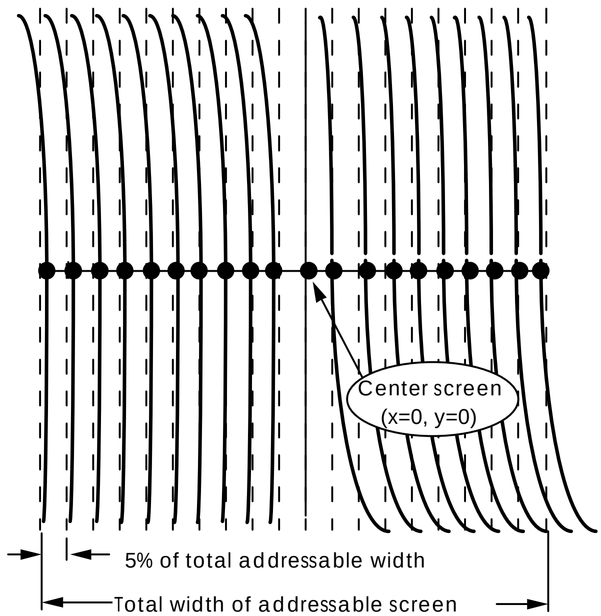


Figure II.18-2. *Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.*

Data: Tabulate x,y positions of equally spaced lines (nominally 5% addressable screen apart) along major (horizontal centerline) and minor (vertical centerline) axes of the raster. If both scans were truly linear, the differences in the positions of adjacent lines would be a constant. The departures of these differences from constancy impacts the absolute position of each pixel on the screen and is, then, the nonlinearity. The degree of nonlinearity may be different between left and right and between top and bottom. The maximum horizontal and vertical nonlinearities (referred to full screen size) are listed in table II.18-1. The complete measured data are listed in table II.18-2 and shown graphically in Figure II.18-3.

Table II.18-1. Maximum Horizontal and Vertical Nonlinearities

Format	Left Side	Right Side	Top	Bottom
1600 x 1200	-1.88%	1.07%	-0.18%	0.13%

Table II.18-2. Horizontal and Vertical Nonlinearities Data

Vertical Lines x-Position (mils)		Horizontal lines y-Position (mils)	
Left Side	Right Side	Top	Bottom
-7712	7588	5696	-5689
-6934	6833	5110	-5114
-6147	6068	4535	-4542
-5356	5295	3964	-3968
-4565	4522	3394	-3401
-3784	3755	2829	-2833
-3010	2992	2263	-2265
-2245	2237	1699	-1702
-1490	1489	1134	-1136
-741	744	567	-571
0	0	0	0

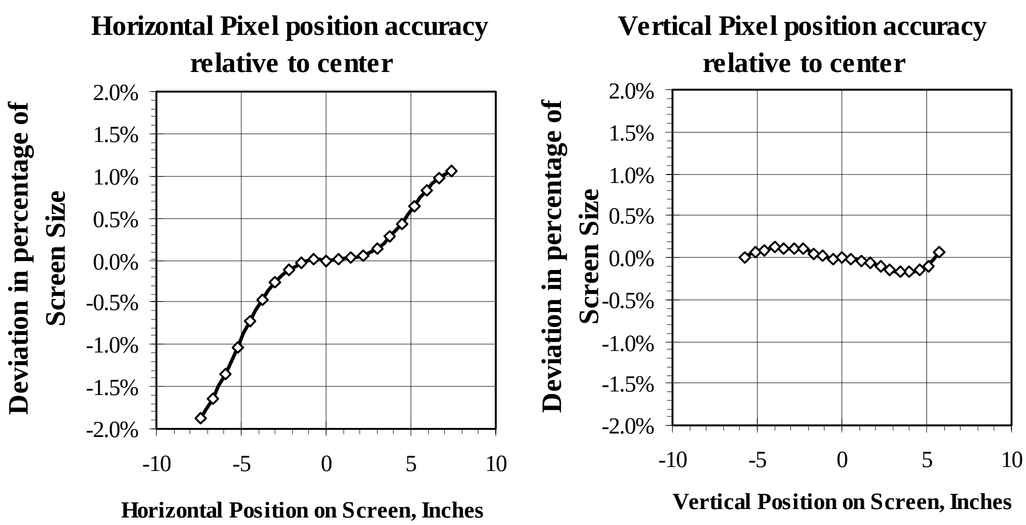


Fig. II.18-5 Horizontal and vertical linearity characteristics.

II.19. Jitter/Swim/Drift

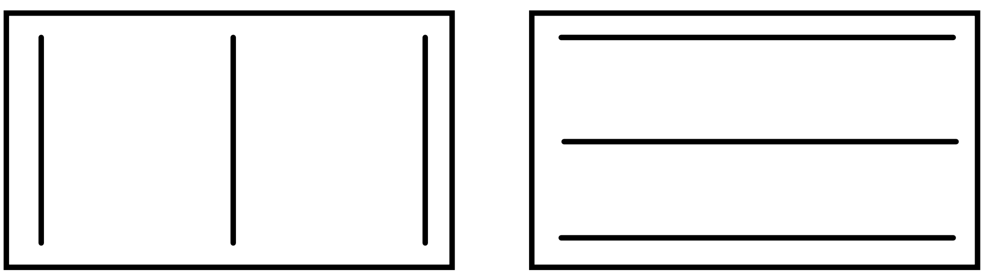
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 6.4, p80.

Maximum jitter and swim/drift were 3.01 mils and 3.15 mils, respectively.

Objective: Measure amplitude and frequency of variations in beam spot position of the CRT display. Quantify the effects of perceptible time varying raster distortions: jitter, swim, and drift. The perceptibility of changes in the position of an image depend upon the amplitude and frequency of the motions which can be caused by imprecise control electronics or external magnetic fields.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.19-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



V-grille for measuring horizontal motion H-grille for measuring vertical motion

1-pixel wide lines

Three-line grille test patterns.
Figure II.19-1

Procedure: With the monitor set up for intended scanning rates, measure vertical and horizontal line jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration as displayed using grille video test patterns. Generate a histogram of raster variance with time. The measurement interval must be equal to a single field period.

Optionally, for multi-sync monitors measure jitter over the specified range of scanning rates. Some monitors running vertical scan rates other than AC line frequency may exhibit increased jitter.

Measure and report instrumentation motion by viewing Ronchi ruling or illuminated razor edge mounted to the top of the display. It may be necessary to mount both the optics and the monitor on a vibration damped surface to reduce vibrations.

Data: Tabulate motion as a function of time in x-direction at top-left corner screen location. Repeat for variance in y-direction. Tabulate maximum motions (in mils) with display input count level corresponding to L_{max} for jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration. The data are presented in Table II.19-1. Both the monitor and the Microvision equipment sit on a vibration-damped aluminum-slab measurement bench. The motion of the test bench was a factor of 10 times smaller than the CRT raster motion.

Table II.19-1. Jitter/Swim/Drift

Time scales: Jitter 2 sec., Swim 10 sec., and Drift 60 sec.

10D corner		**H-Lines**	**V-Lines**	
	Jitter	3.20	2.06	
	Swim	3.53	2.33	
	Drift	3.78	2.55	
Black Tape				
	Jitter	0.191	0.227	
	Swim	0.382	0.316	
	Drift	0.764	0.779	
Less Tape Motion				**maximums**
	Jitter	3.009	1.833	3.009
	Swim	3.148	2.014	3.148
	Drift	3.016	1.771	3.016
Center screen				
	Jitter	2.00	1.71	
	Swim	2.17	1.87	
	Drift	2.38	1.92	
Black Tape				
	Jitter	0.164	0.175	
	Swim	0.234	0.265	
	Drift	0.546	0.683	
Less Tape Motion				**maximums**
	Jitter	1.836	1.535	1.836
	Swim	1.936	1.605	1.936
	Drift	1.834	1.237	1.834

II.20 Warmup Period

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.20, p. 10.

Less than 1 minute warmup time was necessary for luminance stability of Lmin = 0.1 fL +/- 10%.

Objective: Define warm-up period

Equipment: Photometer, test target (full screen 0 count)

Procedure: Turn monitor off for three-hour period. Turn monitor on and measure center of screen luminance (Lmin as defined in Dynamic range measurement) at 1-minute intervals for first five minutes and five minute intervals thereafter. Discontinue when three successive measurements are ± 10% of Lmin.

Data: Pass if Lmin within ± 50% in 30 minutes and ±10% in 60 minutes.

The luminance of the screen (commanded to the minimum input level, 0 for Lmin) was monitored for 120 minutes after a cold start. Measurements were taken every minute. Figure II.20-1 shows the data for 1280 x 1024 format in graphical form. The luminance remains very stable after 49 minutes.

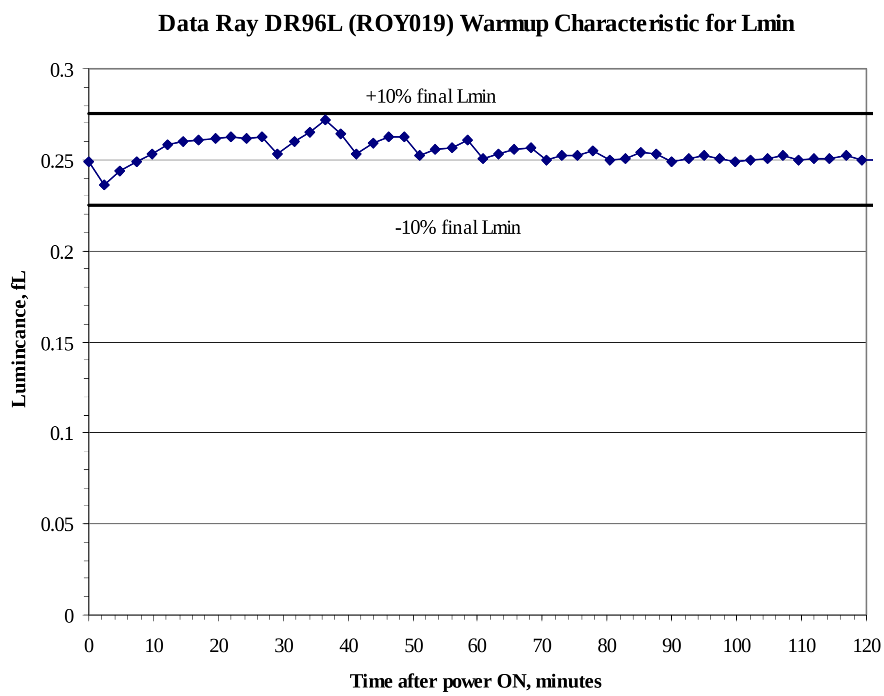


Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 0. (Note suppressed zero on luminance scale).

II.21 Luminance Stability vs. Fill Factor

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.3, p. 26.

Luminance of full screen white in 1024 x 1024 stereo mode increased by more than 75.8% from 215fL to 378 fL as fill factor (target size) was reduced to 10% of full screen. Luminance of other similar monitors certified for IEC change very little (less than 1%) over the same fill factor range.

Center screen luminance was measured for different-sized white patches on a black background (different fill factors). The resulting variation in luminance is plotted in Figure II.21-1 below.

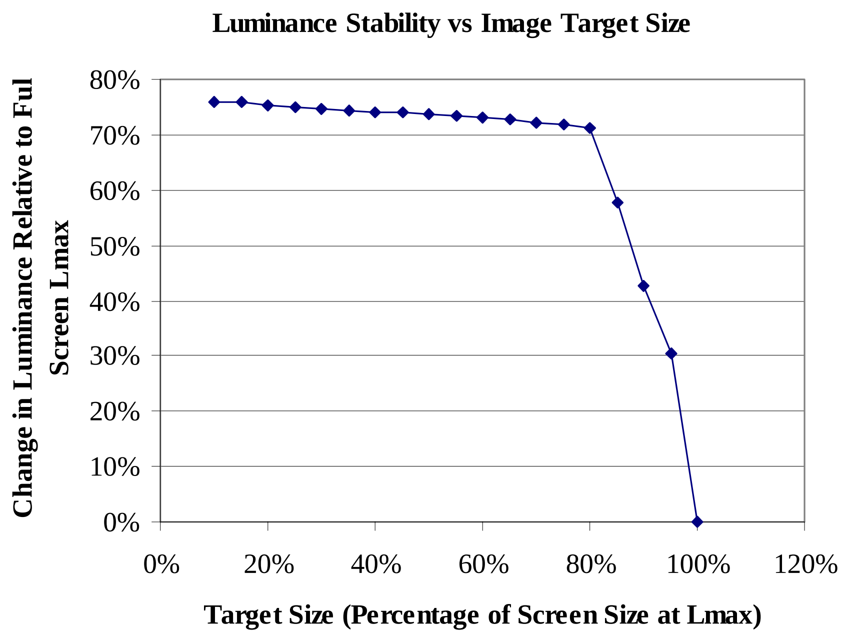


Figure II.21-1. The change in luminance with increasing screen fill factor expressed as a percentage change from the 100% white full screen fill factor luminance level.

Further diagnostic testing revealed different behavior for monoscopic and stereoscopic modes of operation. The data are summarized in Table II.21-1.

The 1600 x 1200 x 72Hz monoscopic mode operation exhibited little or no luminance variation among 20% screen size targets and full screen targets for Lmax values up to approximately 150fL. Beyond 150 fL, full screen luminance clamped to 163 fL, however, the smaller 20% luminance reached levels as high as 248 fL (52% greater than the full screen luminance.)

The 1024 x 1024 x 120Hz stereoscopic mode operation exhibited a nearly constant luminance variation among 20% screen size targets and full screen targets over a substantial range of Lmax settings. With full screen Lmax set as low as 25 fL, the smaller 20% screen sized target luminance increased by 60% to 40 fL. Higher settings of full screen Lmax produced increases in luminance as much as 72%.

Table II.21-1. Luminance Stability

Monoscopic Mode 1600 x 1200 x 72 Hz			**Stereoscopic Mode 1024 x 1024 x 120Hz**		
Target Size		**Luminance Change**	**Target Size**		**Luminance Change**
100%	**20%**		**100%**	**20%**	
24.6 fL	25.0 fL	2%	25.0 fL	40.0 fL	60%
37.8 fL	38.6 fL	2%	46.9 fL	77.0 fL	64%
98.0 fL	100 fL	2%	72.0 fL	121 fL	68%
148 fL	151 fL	2%	129 fL	219 fL	70%
163 fL	199 fL	22%	220 fL	378 fL	72%
163 fL	248 fL	52%			

II.22 Briggs Scores

Reference: SofTrak User's Guidelines and Reference Manual version 3.0, NIDL, Sept. 1994, page 3.

Briggs Scores for the BTP #4 Delta-1, Delta-3, Delta-7 and Delta-15 contrast ratio target sets averaged 12, 46, 57 and 60 , respectively.

The Briggs series of test targets illustrated in Figures II.22-1 were developed to visually evaluate the image quality of grayscale monitors. Three observers selected the maximum scores for each target set shown in Figure II.22-2 displayed on the Data Ray DR96L monochrome CRT monitor driven using a Quantum Data 8701 400MHz programmable test pattern generator. Magnifying devices were used when deemed by the observer to be advantageous in achieving higher scores.

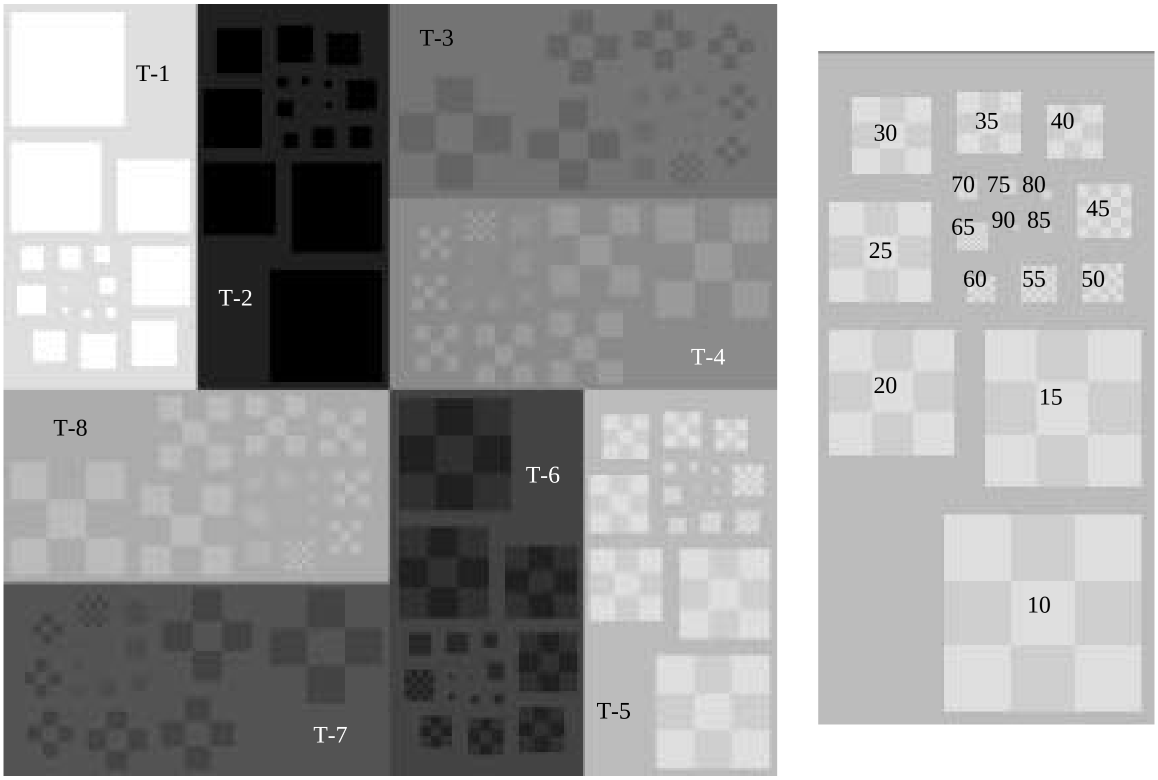


Figure II.22-1. Briggs BPT#4 Test Patterns comprised of 8 targets labeled T-1 through T-8. A series of 17 checkerboards are contained within each of the 8 targets. Each checkerboard is assigned a score value ranging from 10 to 90. Higher scores are assigned to smaller checkerboards.

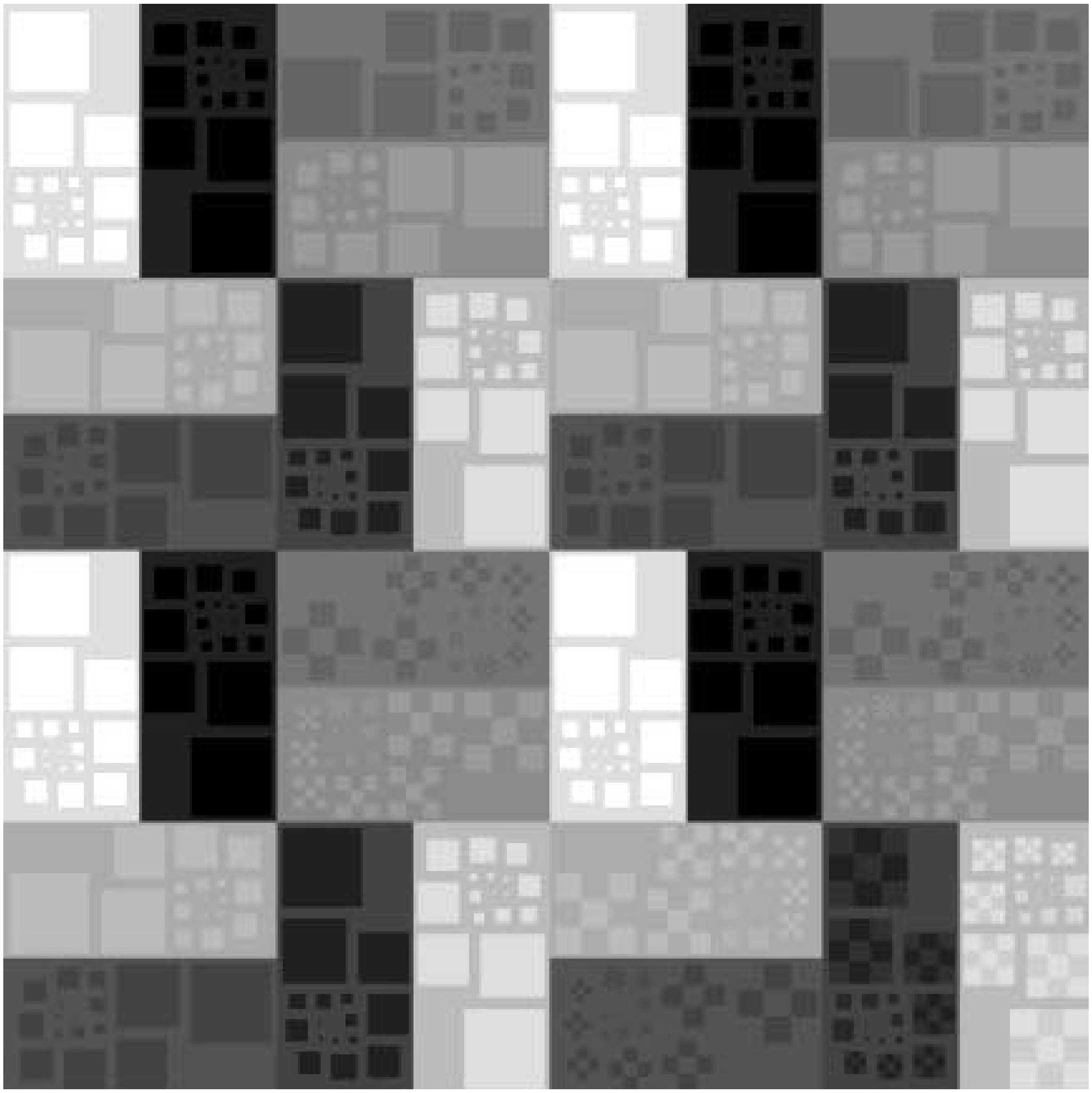


Figure II.22-2. 1024 x 1024 mosaic comprised of four 512 x 512 Briggs BPT#4 Test Patterns. The upper left quadrant contains the set of 8 Briggs targets with command contrast of delta 1. The upper right quadrant contains command contrast of delta. Delta 7 targets are in the lower left quadrant and delta 15 targets are in the lower right.

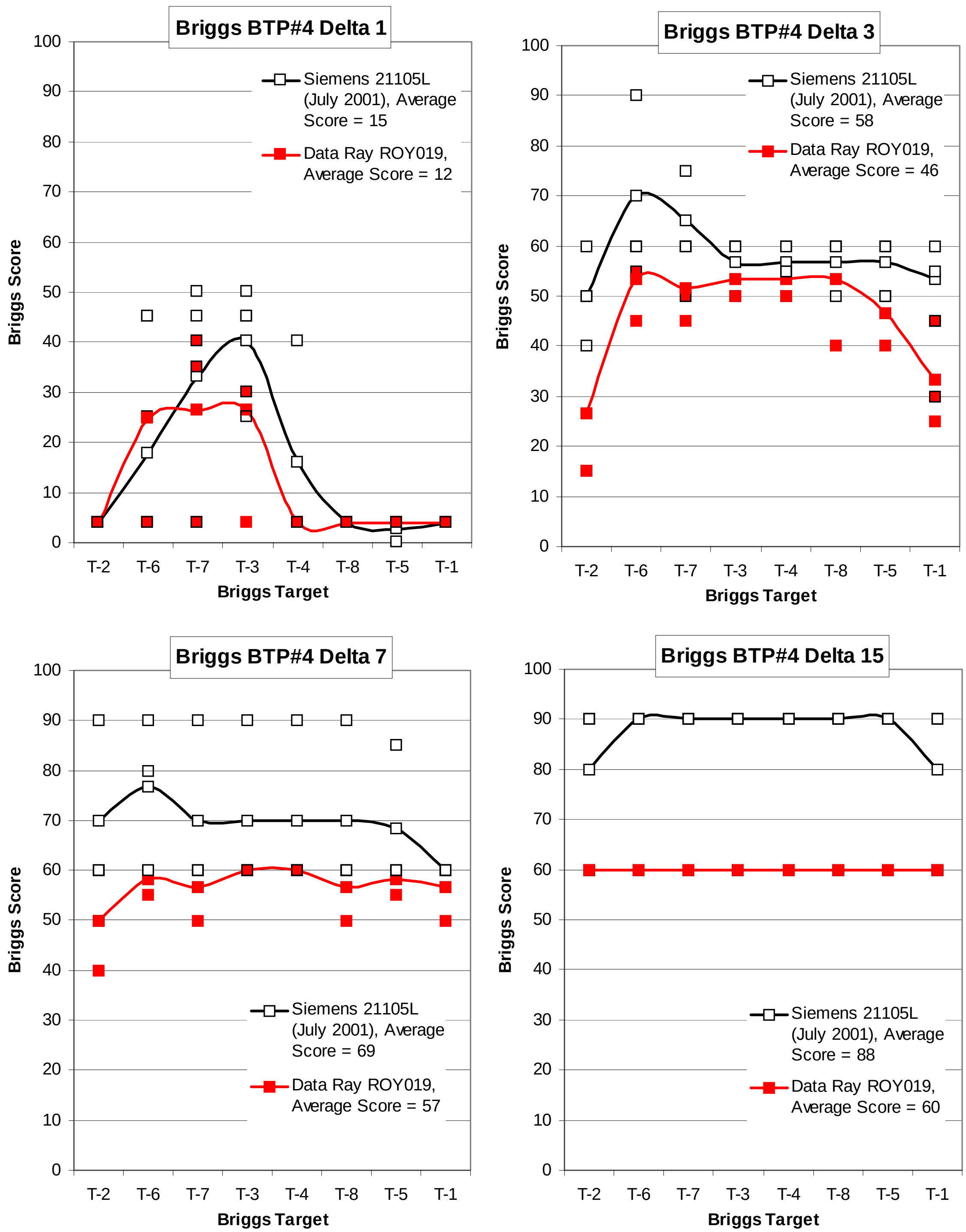


Figure II.22-3. Briggs Scores by three observers for Delta-1, Delta-3, Delta-7 and Delta-15 contrast ratios on BPT#4 Test Pattern for the Data Ray DR96L monitor and, for comparison, on the Siemens 21105L monitor.

Appendix 1 Results of Initial Sample Data-Ray DR96L Monitor Tested July 2000

Results for an initial sample monitor (DR96 Data Ray Engineering Test Sample 4 996005 100486) submitted to NIDL in July 2000 indicated that at least one major aspect of the performance did not meet the IEC required level, namely, contrast modulation. 1-pixel-on/1-pixel-off grille patterns were measured at nine screen points (center, sides, top, bottom, and four corners) at two luminance settings (Lmax full white screen = 93.8 fL and 36 fL) where the grilles were displayed at 50%Lmax. Contrast modulation of vertical grilles was less than the IEC required levels. The contrast modulation requirements for IEC are: Cm Zone A: 35% min., Cm Zone B: 20% min.

Figure A-1. Photo of the upper left quadrant of the second sample monitor screen displaying text.

Data Ray replied with special instructions which were executed by NIDL for resetting the ROY022 monitor to the factory default settings, but the focus did not improve. Center screen linewidths were measured to be 8.3 mils at 83fL and 13.3 mils at 167 fL. The linewidths were much larger at the 12:00 screen position (top of screen) where they were measured to be 32 mils at 83fL and 53 mils at 167fL. The intensity profiles of the lines at 12:00 where flat topped and asymmetric (instead of Gaussian-shaped) indicating an out-of-focus condition.

Table A-1. Contrast Modulation

Results for an initial sample monitor DR96L
Data Ray Engineering Test Sample 4 996005 100486)
submitted to NIDL in July 2000

1600 x 1200
Lmax = 36fL

	Left		Minor						Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	35%	2%			24%	27%			40%	15%
			48%	16%	35%	26%	50%	21%		
Major	61%	7%	58%	16%	55%	25%	62%	26%	68%	27%
			62%	17%	51%	34%	65%	19%		
Bottom	73%	3%			48%	39%			82%	10%

1600 x 1200
Lmax = 92fL

	Left		Minor						Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	50%	12%			46%	32%			55%	21%
			60%	17%	53%	27%	62%	20%		
Major	48%	18%	58%	19%	66%	20%	71%	26%	77%	34%
			62%	16%	55%	37%	72%	21%		
Bottom	55%	11%			49%	48%			82%	24%

The worst case measured values of contrast modulation on the first sample DR96L monitor were: Cm Zone A: 16% min., Cm Zone B 2% min. for Lmax = 36fL, and Cm Zone A: 16% min., Cm Zone B: 11% min. for Lmax = 92fL. We did not measure the stereo performance at the required luminance settings for the first sample monitor. We did, however, confirm that the monitor was able to operate at the stereo timing format (1024 x 1024 x 120Hz).

Results for a second sample monitor (Totoku MDT 2210A, Serial number ROY022, manufactured in November 2000) submitted to NIDL in May 2001 indicated that the monitor was not operating correctly as evidenced by poor focus and large spots size. The manufacturer advised us to check that we were using the correct video signal timings (1600x1200/72Hz, approx. Hf = 89 kHz and 1024x1024/120Hz approx. Hf = 127 kHz. as specified by Data Ray) which impact the phase shift for dynamic focus and astigmatism correction circuits. Using our 400 MHz Quantum Data Fox 8701 programmable test pattern generator, we tried the following timings which comply with the timings provided by Data Ray, but still saw excessive spot astigmatism around the periphery of the screen.

Table A-2. Monitor Timings

	Monoscopic	Stereoscopic
Format	1600 x 1200 x 72Hz	1024 x 1024 x 120Hz
H-rate	89.276 kHz	126.777 kHz
H-active	8.22 uS	5.398 uS
H-blanking	2.98 uS	2.488 uS
V-rate	71.997 Hz	119.998 Hz
V-active	13.441 mS	8.076 mS
V-blanking	0.448 mS	0.256 mS
Pixel	5.138 nS	5.272 nS

A sketch indicating the direction of the astigmatism in the spots at high luminance (168fL) and also at lower luminance (35fL) was sent to the manufacturer along with measured spot contours at screen center and the upper left corner at 168fL in 1600 x 1200 x 72Hz. The contours show a much larger spot at the corner compared to center screen.

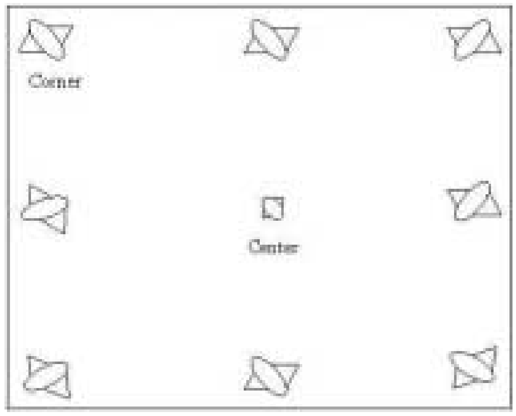


Figure A-2. A sketch indicating the direction of the astigmatism in the spots of the second sample monitor.

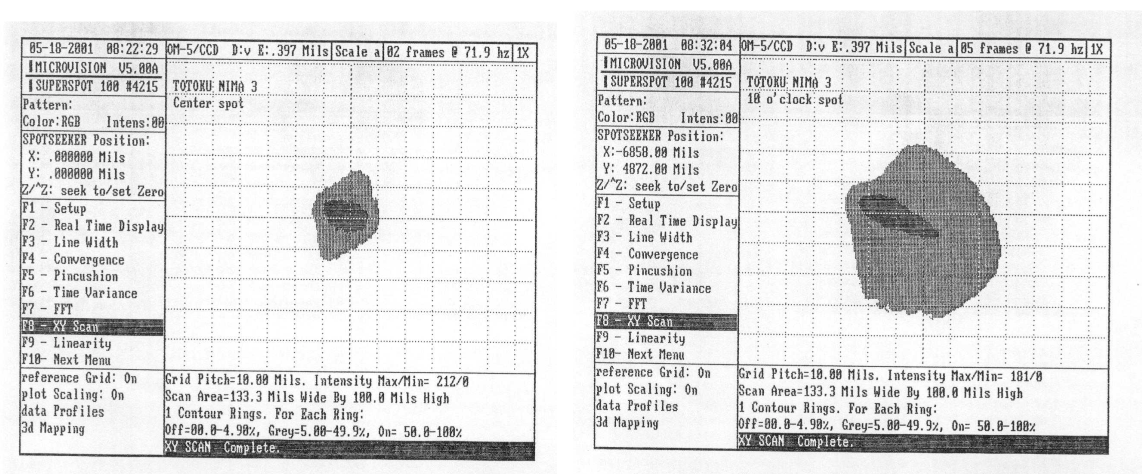


Figure A-3. Measured spot contours for the second sample monitor at screen center and the upper left corner at 168fL in 1600 x 1200 x 72Hz.

We also sent a photo of the upper left quadrant of the screen displaying text. It shows good focus in the lower right of the photo (corresponding to the center of the monitor screen), but the focus degrades towards the corner. The monitor focus and astigmatism settings are incorrect.

Evaluation Datasheet

Results for an initial sample monitor DR96L
Data Ray Engineering Test Sample 4 996005 100486)
submitted to NIDL in July 2000

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC			
vAddressability	1024 x 1024 min.	1600 x 1200	pass
Dynamic Range	25.4 dB	29.7 dB	pass
Luminance (Lmin)	0.1 fL min. ± 4%	0.1 fL	pass
Luminance (Lmax)	35 fL ± 4%	93.8 fL	pass
Uniformity (Lmax)	28% max.	18.3%	pass
Halation	3.5% max.	Not measured	
Color Temp	Not specified	12333 K	
Reflectance	Not specified	Not measured	
Bit Depth	8-bit± 5 counts	Not measured	pass
Step Response	No visible ringing	Clean	pass
Uniformity (Chromaticity)	0.010 delta u'v' max. ± 0.005 delta u'v'	0.001 delta u'v'	pass
Pixel aspect ratio	Square H = V± 6%	Set to square	pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	Not measured	
Cm, Zone A	35% min.	16%	fail
Cm, Zone B	20% min.	11%	fail
Pixel density	72 ppi min.	Approx. 100 ppi	pass
Straightness	0.5% max ± 0.05 mm	Not measured	
Linearity	1.0% max ± 0.05 mm	Not measured	
Jitter	2 ± 2 mils max.	Not measured	
Swim, Drift	5 ± 2 mils max.	Not measured	
Warmup time, Lmin to +/- 50%	30 mins. Max ± 0.5 minute	Not measured	
Warmup time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	Not measured	
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 72 Hz	pass
STEREOSCOPIC			
Addressability	1024 x 1024 min.	1024 x 2048 (I)	pass
Lmin	0.1 fL min. ± 4%	Set to 0.035 fL	To be remeasured
Lmax	30 fL min ± 4%	6.4fL (Set for 36 fL at CRT screen)	To be remeasured
Dynamic range	24.77 dB min	Not measured	
Uniformity (Chromaticity)	0.02 delta u'v' max ± 0.005 delta u'v'	Not measured	
Refresh rate	60 Hz per eye, min	60 Hz, per eye	pass
Extinction Ratio	20:1 min	29.9:1 (n)	pass